Deep Tillage of Irrigated Pullman Clay Loam— A Long-Term Evaluation

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ABSTRACT

PULLMAN clay loam (Torrertic Paleustolls) is the most extensively irrigated soil type in the United States. It is slowly permeable to water, but is responsive to deep tillage for increasing water intake and profile storage. A one-time deep moldboard plowing to 0.4-, 0.6-, and 0.8-m depths was tested in 1966 for modifying the slowly permeable B2t horizon and compared with conventional tillage to 0.2 m. The 0.6-m plowing depth fully penetrated the slowly permeable B2t, while the 0.8-m depth loosened and mixed an increment of more permeable clay. This paper reports long-term residual effects for eight crops during 1972-79.

After moldboard plowing to 0.2 m to restore surface-layer permeability, residual effects of deep tillage increased irrigation water intake from 120 to 240 mm in 1975 and from 170 to 280 mm in 1978, indicating no diminishment of the effect with time. After primary tillage, irrigation and wheel traffic caused surface soil consolidation, which greatly reduced residual deep-tillage effects on water intake during the growing season. During some periods of the study, deep-tillage had little to no effect on intake, but the effect was restored by conventional moldboard plowing to 0.2 m. During two seasons of sorghum (*Sorghum bicolor* L. Moench) and two of corn (*Zea mays* L.), residual deep tillage increased sorghum grain yields in the range of 880 to 1,250 kg/ha, and corn yields in the range of 1,280 to 1,630 kg/ha. The increased water intake and deeper profile wetting of deep-tillage plots delayed the beginning and reduced the severity of plant water stress. We concluded that deep-tillage is a practical method for increasing water intake of a slowly permeable structured clay and associated crop yield, particularly on the normally drier, lower parts of graded furrow irrigated fields where it can be used in association with reduced tailwater runoff.

INTRODUCTION

About 1.2 of the 2.5 million hectares of irrigated soils in the Southern High Plains are slowly permeable swelling clays. These soils are irrigated predominatly by the graded-furrow method. Pullman clay loam (fine, mixed, thermic Torrertic Paleustolls) is the most widely occurring soil type in the area (Taylor et al., 1963). Water intake during graded-furrow irrigation averages about 90 mm during 12- to 24-h irrigation sets and wets the soil to about 0.6-m depth (Musick et al., 1971, 1973). Basic intake rates decline to about 2 to 3 mm/h after 4 to 5 h of application time in graded furrows. Most field crops deplete soil water to at least the 1-m depth, and some can withdraw water from the 2- to 3-m depth.

In the Southern High Plains, declining groundwater levels limit pump outputs, thus limiting the area that a farmer can irrigate. To limit irrigation demand during peak-use periods, it is desirable for plants to meet transpirational demand as much as possible from profile water storage. Deep tillage of slowly permeable clays developed as a practice for increasing irrigation water intake rates and depth of profile wetting. This practice is particularly well adapted for use on the normally drier, lower parts of graded-furrow fields.

Jensen and Sletten (1965) found that chiseling Pullman clay loam when the upper profile was in a dry condition after harvest of sorghum (*Sorghum bicolor* L. Moench) doubled average water-intake rates during the next crop season compared with shallow tillage. The soil was chiseled to the 0.4-m depth on 0.5-m spacings. The effect declined to a 53 percent increase in intake rate the second season, 31 percent the third, and 20 percent the fourth. Chiseling after harvest of wheat following partial rewetting by rainfall, increased water intake rates by 33 percent the first season, 17 percent the second, and 5 percent the third.

Hauser and Taylor (1964) found that disk-plowing Pullman clay loam to 0.6 m increased water intake rates by 90 percent. Although intake rates declined during a 3-year period, the relative effect of deep tillage when compared with conventional tillage remained about constant. Vertical slots on 2.0-m centers without mulch had very little effect on water intake rates.

Eck and Taylor (1969) found that with preplant irrigation only, profile modification (mixing with a ditching machine) to 0.9 and 1.5 m increased grain sorghum yields by 66 and 80 percent, respectively, over a 3-year period. Water-use efficiencies were increased 41 and 25 percent, respectively. When the level border plots were adequately irrigated, deep tillage had little or no effect on grain sorghum yields (Jensen and Sletten, 1965; Hauser and Taylor, 1964).

Mathers et al. (1971) determined that deep tillage of Pullman clay loam to 0.4 and 0.6 m increased yields of sugarbeet under adequate irrigation. The lower bulk densities and increased intake rates reduced the time that irrigation and rainfall remained on the soil surface of level border plots, reduced sprangled root growth associated with poor aeration, and increased yields.

Menzel et al. (1968) reported that deep plowing Pullman clay loam to 0.9 m with the moldboard plow described by James and Wilkins (1972) doubled the yield of irrigated sugarbeet and soybean and increased the yield of irrigated cabbage and sudangrass by 60 percent in comparison with rotary tillage to 0.2 m.

The research reported in this paper was begun in 1966 as a one-time moldboard plowing to 0.4-, 0.6-, and

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0.8-m depths on graded-furrow irrigated Pullman clay loam at Bushland, TX, and compared with conventional tillage that did not exceed a 0.2-m depth. Results through 1972 were reported by Schneider and Mathers (1970), Mathers et al. (1971), and Musick and Dusek (1975). This paper assesses continued long-term residual effects through 1979, change with time, and implications for irrigated crop production on slowly permeable clays.

PROCEDURE

Residual deep-tillage treatments were tested on duplicated main plots 12.2 by 305 m. Plots were shortened 91 m to increase the number for the 1973-75 tests, which involved a wheat-sorghum-fallow sequence in which disk tillage was compared with chemical fallow. As this cropping sequence was terminated, plot length was increased to 207 m for the 1976-77 tests and then increased to the original 305 m for the 1979 test.

In addition to the eight wheat, sorghum, and corn crops planted for normal harvest, winter wheat was planted after moldboard plowing to 0.2 m in the fall of 1975 and 1978 to evaluate intake during irrigation for crop emergence and to provide a winter cover crop after fallow. The wheat was removed by disk tillage about 2 months before planting corn or sorghum. Fertility was adequate for high yields, with N application rates ranging from 80 to 220 kg/ha, depending on water treatment, crop, and year. Nitrogen was applied as anhydrous ammonia before planting.

Irrigation water was applied through gated pipe with application to individual furrows measured by the bucket-stopwatch method. Furrow flow rates were set at selected amounts within the range of 0.5 to 1.0 L/s per furrow depending on plot length, furrow spacing, and expected intake rate. Duplicate runoff measurements were made from four furrows per plot with individually calibrated H-flumes equipped with FW-1 water stage recorders. Under most conditions, runoff was allowed for 3 to 8 hours.

Soil water content was sampled by the gravimetric method in 0.3-m increments to 1.8 m at the beginning and end of season and before and after selected irrigations. Some samples were taken to the 3-m depth to assess deep wetting under conditions of high irrigation water intake.

For selected test conditions, plant leaf water-potential data were taken by the pressure chamber method (Scholander et al., 1965) within 2 hours after solar noon to assess deep tillage effects on severity of plant water stress.

Wheat was grown in 1-m bed-furrow spacing with either 0.2- or 0.25-m row spacing. Sorghum and corn were grown in 0.75-m bed-furrow spacing planted single rows per bed. Wheat yields were determined by combine harvesting entire plots. Sorghum and corn yields were determined by sampling four to eight 5-m^2 samples depending on plot length; a plot thresher was used for sorghum heads and corn ears were hand shelled after oven drying. Sorghum and corn yields are adjusted to 14 percent moisture, wet weight basis.

The Pullman profile has a clay loam A horizon in the 0- to 0.2-m tillage zone, clay B2t and B3 horizons that extend to about the 1.2-m depth, and a calcic C horizon. The soil has a relatively dense, bolcky structure below the surface tillage layer, with bulk densities in the range of 1.5 to 1.7 g/cm^3. The profile is slowly permeable when wet, with basic intake rates of 1 to 3 mm/h. The slowly permeable B2t horizon extends from normal tillage depth to about 0.6 m. The clay type is predominantly montmorillonite. During major drying, the soil develops shrinkage cracks that result in a relatively high initial water-intake capacity of about one-half the total intake during irrigation. Plant-available soil water for the 1.2-m major root zone, between -1/3 and -15 bars, is 160 mm (Musick et al., 1976).

RESULTS

Irrigation-Water Intake

The major plant growth and yield effect from deep tillage is associated with increased water intake and profile storage. Therefore, irrigation-water intake was selected as the most important soil physical property in assessing the long-term residual effect of the 1966 moldboard plowing. During 1973-79, total water intake was measured during the 30 irrigations. Table 1 gives the dates of all irrigations during this period and the amounts of seasonal rainfall; Table 2 presents intake data for irrigations of each crop as preseason and seasonal amounts and the total for the season.

While the study was being managed in a wheat-sorghum-fallow cropping sequence during 1973-75, only relatively shallow surface tillage was done with the disk, sweep, lister or disk bedder, and bed-furrow cultivation with the sweep-rod weeder or rolling cultivator. None of these operations loosened the surface 0.2-m layer enough to fully restore the intake capacity of the deep tillage treatments. During this period of shallow tillage, residual deep tillage effects on irrigation intake were modest or did not occur.

TABLE 1. PLANTING DATES, IRRIGATION DATES, AND SEASONAL RAINFALL

Year	Crop	Planting date	Irrigation: Treatment*	Irrigation: Dates	Seasonal rainfall, mm
1973	Wheat	30 Oct. 1972	I-1	7 June	332
1973	Sorghum	5 June	I-1	20 June, 19 July, 20 Aug.	156
1974	Wheat	29 Sept. 1973	I-1	29 May	216
	Sorghum	24 June	I-1	26 June	379
1975	Sorghum	9 June	I-1	13 June, 13 Aug.	175
			I-2	13 June, 13 Aug., 2 Sept.	
1975	Wheat	Emergence irrigated 17 Oct., removed Mar. 1976 for corn.			
1976	Corn	14 Apr.	I-1	27 Apr., 15 July, 2 Aug.	262
1977	Corn	28 Apr.	I-1	3 May, 27 June, 20 July	345
			I-2	3 May, 20 June, 8 July, 21 July, 3 Aug.	
1978	Wheat	Emergence irrigated 14 Sept., removed Mar. 1979 for sorghum.			
1979	Sorghum	9 May	I-1	15 May, 17 July, 16 Aug.	267
			I-2	15 May, 10 July, 31 July, 16 Aug., 5 Sept.	

*Treatments I-1 and I-2 were different irrigations applied within a crop and season.

TABLE 2. IRRIGATION-WATER INTAKE AND GRAIN YIELDS, 1973-79

			Irrigation 1†				Irrigation 2†			
		1966 tillage depth, m	Intake, mm			Yield, kg/ha	Intake, mm			Yield, kg/ha
Year	Crop		Preseason	Seasonal	Total		Preseason	Seasonal	Total	
1973	Wheat	0.2	None	151	151	3,210c*				
		0.4	None	147	147	3,450b				
		0.6	None	154	154	3,640ab				
		0.8	None	151	151	3,670a				
1973	Sorghum	0.2	58	156	214	4,880a				
		0.4	74	169	243	5,340a				
		0.6	69	180	249	5,310a				
		0.8	74	181	255	5,350a				
1974	Wheat	0.2	None	86	86	NH‡				
		0.4	None	100	100	NH				
		0.6	None	104	104	NH				
		0.8	None	111	111	NH				
1974	Sorghum	0.2	117	None	117	3,160b				
		0.4	126	None	126	3,240b				
		0.6	143	None	143	3,360ab				
		0.8	137	None	137	3,620a				
1975	Sorghum	0.2	65	82	147	4,940c	65	178	243	6,040c
		0.4	82	89	171	5,430b	82	186	268	6,570b
		0.6	84	88	172	5,460b	84	192	276	6,950ab
		0.8	74	86	160	5,890a	74	172	246	7,290a
1976	Corn	0.2	72	92	164	6,320c				
		0.4	118	86	204	7,460b				
		0.6	138	98	236	7,950a				
		0.8	142	110	252	7,900a				
1977	Corn	0.2	135	228	363	8,790b	135	426	561	10,020b
		0.4	151	266	417	9,270b	151	482	633	11,200a
		0.6	259	318	577	10,130a	259	499	758	10,880ab
		0.8	242	286	528	10,010a	242	489	731	11,300a
1979	Sorghum	0.2	124	175	299	8,040b	124	431	555	9,080b
		0.4	171	219	390	8,370b	171	444	615	9,960a
		0.6	199	215	414	9,030a	199	443	642	9,880a
		0.8	196	221	417	8,510ab	196	438	634	9,770a

*Within each crop, column means followed by the same letter are not significantly different at the 5% level by Duncan's multiple range test.
†Irrigations 1 and 2 were different number of irrigations applied within a crop and season.
‡NH - not harvested as individual plots because of hail damage.

To assess the full magnitude of the residual deep-tillage effect, we moldboard-plowed the plot area to 0.2 m before seeding wheat in 1975 and 1978. The residual effects on irrigation-water intake during irrigation of wheat for emergence are presented in Fig. 1 and compared with the effect obtained after loosening the 0.2-m depth with a vibrating chisel before planting in 1969. Deep tillage increased intake from 120 to 240 mm in 1975 and from 170 to 280 mm in 1978. The range in increased intake from deep tillage measured in 1969 was 90 to 230 mm.

The effect of deep tillage on water intake after major loosening of the surface soil was linear with increasing depth to 0.6 m, the bottom of the slowly permeable B2t horizon. Increasing the depth from 0.6 to 0.8 m had a small additional effect. However, when intake was averaged for the 66 irrigations measured during the duration of the study, increasing the tillage depth from 0.6 to 0.8 m had no effect, while an average linear effect was measured with increasing depth to 0.6 m (Fig. 1).

Comparing the average effect of the 36 measured irrigations during the 1966-72 period with the 30 irrigations during the 1973-79 period suggests that the average effect has not changed with time. Visual examination of the profile mixed by the moldboard plow in 1966 indicates a continued major change in structure from blocky peds with distinct, slick clay faces to a crumb-type structure. This change in structure has strongly persisted with time. In addition to the moldboard plowing causing major disruption in structure, it caused some vertical

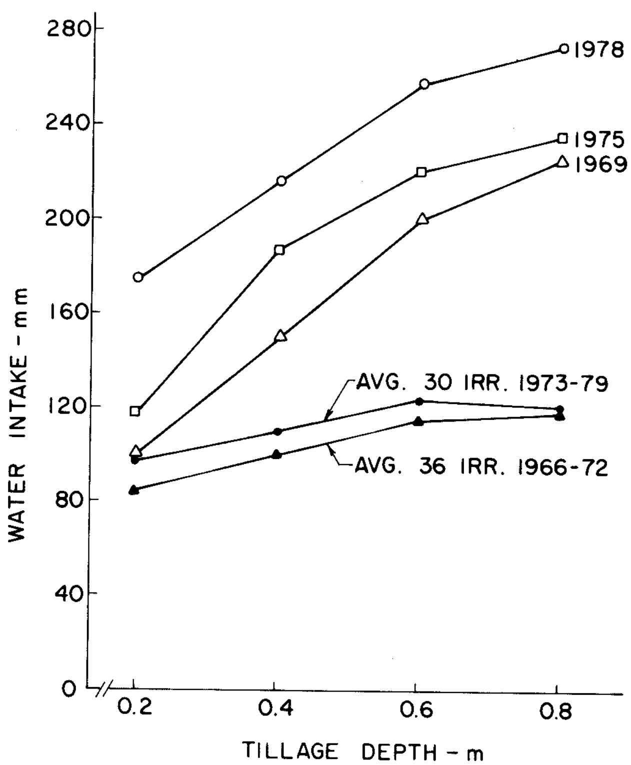

FIG. 1 Effect of residual deep tillage on increased irrigation-water intake after moldboard plowing to 0.2 m in 1975 and 1978 and after loosening to 0.2 m with a vibrating chisel in 1969. These "potential" long-term effects are compared with average effects from 36 irrigations during 1966-72 and 30 during 1973-79.

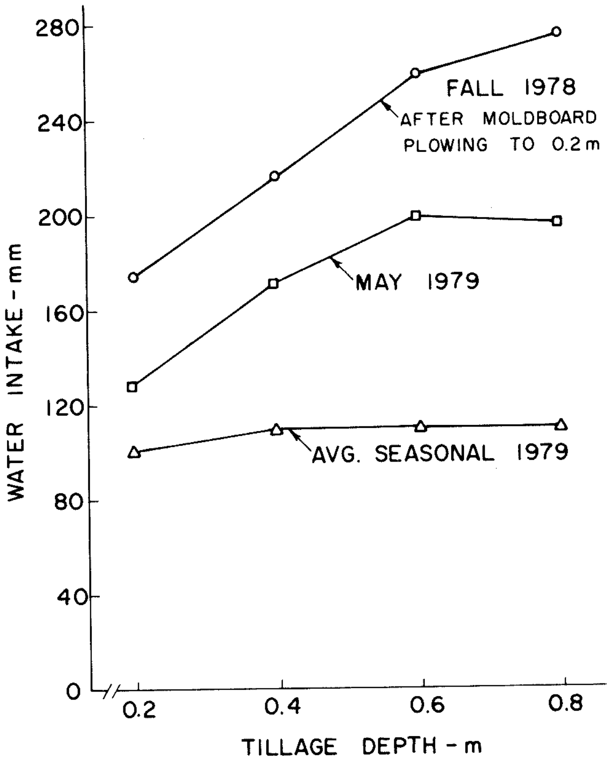

FIG. 2 Effect of residual deep tillage on irrigation-water intake during emergence irrigation of wheat after moldboard plowing to restore surface soil permeability and during emergence and seasonal irrigations after removal of wheat in March by disk tillage.

mixing of topsoil with the B2t clay subsoil. This change of structure is considerably more drastic than the change that occurs from a one-time chiseling of Pullman clay loam.

After the surface soil layer was loosened to 0.2 m by tillage, irrigation caused this layer to reconsolidate, and residual deep-tillage effects on water intake were reduced during subsequent irrigations. This reduced effect is illustrated in Fig. 2. Intake effects though reduced were still pronounced during emergence irrigation of sorghum in May 1979 following wheat removal by disk tillage. After soil consolidation from this irrigation, and possible compaction from wheel traffic, very little effect of deep tillage was evident during summer irrigations. Fig. 2 shows a slight average effect on increased intake from the 0.2 to 0.4 m tillage depth, but no further effect from increasing depth to 0.8 m. These data suggest that the condition of the 0.2-m surface soil layer largely controls irrigation-water intake most of the time, and that periodic loosening of the surface layer is required to increase intake to the potential of subsoil permeability.

Intake for the 66 irrigations over the 14-year period for normal tillage that did not exceed the 0.2-m depth averaged 90 mm (Fig. 1). Although intake varied widely, depending primarily on looseness or consolidation of the surface soil and the profile water content, it was seldom less than one-half or more than twice the long-term average of 90 mm.

Grain Yields

Grain yields are presented in Table 2 for seven of the eight crop seasons tested during 1973-79. Individual plot yields were not taken for the 1974 wheat crop because of hail damage. Wheat planted in the fall of 1975 and 1978 to provide a winter cover was used to assess water-intake effects after moldboard plowing the 0.2 m surface tillage zone and was removed by disk tillage the following spring.

Deep tillage during the 1973-74 tests of wheat and sorghum has a modest yield-increase effect of about 400 to 500 kg/ha. The residual effect of deep tillage was limited during this period because of the use of predominantly shallow tillage. The residual deep-tillage effeect on water intake and grain yields was greater during 1975-79; the yield response was greater for corn than for sorghum because deep tillage had a greater intake effect during the two corn seasons. In 1975 and 1979, the maximum sorghum yield response was in the range of 880 to 1,250 kg/ha and averaged 15.5 percent. In 1976 and 1977, the maximum corn yield response was in the range of 1,280 to 1,630 kg/ha and averaged 17.9 percent. The increased water intake and depth of profile wetting caused major effects at times on plant growth, height, and severity of plant water stress.

TABLE 3. EFFECT OF RESIDUAL DEEP TILLAGE ON LEAF WATER POTENTIAL OF SORGHUM DURING GRAIN FILLING UNDER STRESS CONDITIONS, I-1 TREATMENT, AND AFTER TERMINATION OF STRESS BY IRRIGATION, I-2 TREATMENT, 1975

	Leaf water potential with indicated residual tillage depth, bars			
Conditions	0.2 m	0.4 m	0.6 m	0.8 m
I-1 during stress				
Sept. 1	-22.7	-21.1	-17.4	-16.9
8	-26.0	-24.7	-24.0	-23.1
15	-25.9	-23.7	-23.4	-23.7
19	-29.6	-28.6	-27.3	-28.2
Avg.	-26.0	-24.5	-23.0	-23.0
I-2 during stress				
Sept. 1	-26.6	-26.0	-23.3	-21.6
After Sept. 2 irrigation				
Sept. 8	-17.5	-15.6	-14.9	-14.8
15	-14.9	-15.0	-14.9	-13.6
19	-18.8	-15.4	-14.7	-14.5
Avg.	-17.1	-15.3	-14.8	-14.3

Leaf water potentials taken during grain filling of sorghum in 1975 are presented in Table 3 to illustrate the deep-tillage effect in reducing severity of plant water stress. Afternoon water potentials measured in an upper leaf were in the range of -14 to -17 bars for nonstredded sorghum plants. Potentials declined to -28 to -30 bars under conditions of severe plant water stress as appreciable lower-leaf desiccation occurred during grain filling. On September 1, plants on conventional-tillage plots had leaf water potentials 5 to 6 bars lower than plants on plots deep-tilled to 0.8 m and averaged 3 bars lower for the four sampling dates during an 18-day period. Plant water stress on 1-2 plots was terminated by irrigation on September 2. On September 19, none of the deep-tillage plots were stressed, while the normal-tillage plots were beginning to develop stress at -18.8 bars. The reduced plant water stress on deep-tillage plots resulted in increased yields (Table 2).

DISCUSSION

The 14-yr evaluation of a one-time moldboard plowing performed in 1966 indicated a major increase in permeability of a slowly permeable B2t horizon. Intake tests in 1975 and 1978, after moldboard plowing to 0.2 m had restored surface-soil permeability, indicated that the deep-tillage effect had not diminished with time. Results to date indicate that the effect will likely continue for many years.

Graded-furrow fields on Pullman clay loam are predominantly 0.8 km long and are irrigated mostly by 24-h sets with water advancing to the end of the field in about 12 to 18 h. Water intake is less on the lower part of the field because of reduced intake opportunity time, and yields are normally about 10 to 20 percent lower on the drier, lower part of the field (Musick and Dusek, 1974; Schneider et al., 1976). Running irrigation water until the lower part of the field undergoes major wetting can result in major end-of-field tailwater runoff. We measured runoff from farmers' fields in the range of 20 to 35 percent of the water applied. Although tailwater runoff is ofter reused, losses from collection ditches, pit storage, and reapplication in reuse systems can be appreciable. Since deep tillage is effective in increasing water intake rates, it can permit a reduction in time and amount of tailwater runoff. The best application of deep tillage is to increase water intake and storage on the lower part, which normally is drier and has lower yields. On a 0.8-km field, deep tillage would normally be needed on only about the lower one-fourth to one-third of the field. A larger lower field section can benefit from deep tillage on the steeper slopes, where it is more difficult to obtain adequate wetting of the profile. As the irrigation water level is increased, increasing the water intake by deep tillage will have a reduced effect or no effect on yield. Deep tillage of entire fields can result in profile drainage losses on the upper part. Therefore, deep tillage of the upper part of the field is not recommended, unless it is desired to lower soil density for a root crop such as sugarbeets (Mathers et al., 1971).

The long-term assessment of deep-tillage effects provides an interesting insight into profile control of water intake rates on a slowly permeable clay. We previously assumed that the slowly permeable B2t horizon controlled intake quantity. Although the increased permeability of the deep-tilled B2t horizon was not appreciably reduced over the 14-year period, most of the time deep tillage had little effect on water intake. This suggests that under normal irrigation and tillage conditions for crop production, the consolidation of the surface soil layer by irrigation and by wheel and implement traffic during secondary tillage causes this layer to largely control water intake quantity. This points out the importance of loosening the 0.2-m surface layer by tillage between crops where the B2t hoizon below has been previously deep tilled.

Soil water data indicated that the depth of major depletion by grain sorghum and corn was about 1.2 m and that deep tillage had little effect on depletion depth. Field research at Bushland has shown that sunflower, sugarbeet, and alfalfa can deplete soil water to the 2- to 3-m depth (Unger, 1978; Jones, 1978; Eck et al., 1977; Winter, 1980). Since deep tillage can result in deep profile wetting, water-use efficiency should be enhanced by periodically growing a crop with ability for deep water extraction. Sunflower or sugarbeet could be grown under limited irrigation and utilize much of the water stored in the 1- to 3-m depth that would otherwise be lost to deep percolation. Deeper-than-normal profile water storage can be effectively utilized to reduce peak seasonal irrigation-water demands (Musick and Dusek, 1975).

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